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Geophysical Explorations at Sylvester Manor

Kenneth L. Kvamme

Geophysical surveys were undertaken at the Sylvester Manor Estate, on Shelter Island, New York, in the summer of 2000. This work helped identify and map components of the buried cultural landscape at this plantation where Dutch, English, Native Americans, and enslaved Africans labored in the second half of the 17th century and later. A second goal was to map features of historic gardens that are known to have existed, and explore the possibility of cultural features in a distant "West Peninsula" area. Ground-penetrating radar, magnetic gradiometry, and electrical resistance surveys were employed. The electrical resistance data, acquired at 25 cm and 50 cm target depths, best define architectural features in the form of linear and right angle anomalies that probably represent pavements or building foundations. Their distributions suggest two grid orientations in the layout of historic structures. The magnetic map complements the resistance data, indicating a number of linear alignments of highly magnetic stone, a general scattering of ferrous metal artifacts, and a region that probably represents a dumping ground or midden. The ground-penetrating radar data frequently offers more detail, and gives specific indications of depth to features. Anomalies in the historic garden area most likely represent earlier garden features, including flower beds, walkways, and cart tracks. The geophysical data also reveal a number of former roads, trails, and pipelines. In some instances, these findings are compared against subsequent excavations, revealing both successes and shortcomings of archaeological geophysics.

Des relevés géologiques ont été entrepris pendant l'été 2000 au domaine du Sylvester Manor, à Shelter Island dans l'état de New York. Ces travaux ont permis l'identification et le relevé des composantes de paysages culturels enfouis sous cette plantation où ont œuvré, à partir de la deuxième moitié du XVII^e siècle, hollandais, anglais, autochtones et esclaves d'origine africaine. Le projet a aussi eu pour but de produire un relevé d'éléments de jardins historiques dont l'existence avait été établie et d'examiner la possibilité que la région de la péninsule ouest puisse inclure des éléments culturels. Les méthodes de géoradar, de gradiométrie magnétique et de résistivité électrique ont été utilisées pour produire un relevé. Les données de résistance électrique, acquises à une profondeur de 25 cm et 50 cm, présentent les éléments architecturaux sous forme d'anomalies de formes linéaire et à angle droit, représentant vraisemblablement un pavage ou des fondations d'édifices. Leur distribution suggère que les structures historiques étaient aménagées sur un plan formé de grilles orientées de deux manières différentes. Le plan de gradiométrie magnétique enrichit les données de résistivité électrique indiquant des alignements de pierre hautement magnétique, des artefacts en métal ferreux éparpillés d'un bout à l'autre, et un secteur représentant sans doute un dépôt de déblais ou une fosse à déchets. Les données obtenues par le géoradar offrent habituellement plus de détails que les autres méthodes, et permet l'obtention d'indices spécifiques sur la profondeur des vestiges. Les anomalies observées dans le secteur des jardins historiques représentent sans doute des éléments d'aménagements paysagers anciens dont les plates-bandes, les allées et les pistes de chariots. Les données géoradar révèlent aussi bon nombre d'anciennes routes, de sentiers et de pipelines. Dans certains cas, ces découvertes sont comparées aux résultats de fouilles subséquentes, révélant les succès et les lacunes de l'application de méthodes géophysiques au domaine de l'archéologie.

Introduction

Geophysical survey methods provide a cost-effective means for the acquisition of archaeological information important to several areas of a project. They measure physical properties every meter or less systematically over broad areas to reveal subsurface patterns. Archaeologically useful results derive from contrasts between the measurements. In homogeneous soils measurements will tend to be

relatively uniform. If a buried object or constructed feature intrudes within a unit, such as a historic pit, stone wall, foundation, or fire hearth, its different physical properties will yield changes in the geophysical measurements recorded at the surface, or a contrast against the surrounding matrix. These different measurements are referred to as *anomalies* until their sources can be identified—a task that often requires excavation.

Mapping the full shape or distribution of anomalies over an area can facilitate recognition of their sources. Although the investigation of small areas may reveal anomalies of potential archaeological interest, large-area surveys make it easier to recognize and interpret culturally meaningful constructions. This occurs because many cultural phenomena, particularly architectural remains, tend to exhibit regular forms as lines, squares, rectangles, or circles (these patterns occur much less frequently as products of nature). If a small-area survey reveals a linear anomaly it is difficult to ascertain whether it might represent a road or trail, a wall, or the side of a larger structure. A large-area survey, however, can reveal an anomaly's full extent and indicate its association with other site components. Surveying large areas therefore aids recognition of culturally generated anomalies (Kvamme 2003).

Through geophysics, management and planning maps of subsurface archaeological features can be created that document the basic structure and layout of sites. The placement of expensive excavations and testing programs can be guided to specific anomalies of interest, producing large cost savings in site explorations. Primary data for settlement pattern research and analysis can also be generated when details of a site and its components are clearly mapped. In achieving these goals, the use of multiple geophysical methods is important because it increases the likelihood of detecting subsurface changes of some kind. In other words, various sensors are designed to detect different physical properties; using several makes it more likely that complementary features will be located (Clay 2001; Kvamme 2006). These principles were employed in the geophysical surveys at Sylvester Manor.

Geophysical Instrumentation, Methods, and Theory

Three distinct geophysical survey techniques were employed at Sylvester Manor: magnetic gradiometry, electrical resistance, and ground-penetrating radar (GPR). Each of these methods is generally sensitive to a different aspect of subsurface archaeological deposits. All employed a common set of field methods.

Field Methods

Geophysical investigations at Sylvester Manor were conducted within survey blocks

that controlled the placement and movement of instruments over the landscape. Blocks of 20 × 20 m were generally employed, although smaller ones were sometimes required in confined areas. These blocks were established within the arbitrary coordinate system established by the University of Massachusetts Boston (UMass Boston) archaeological field school. The coordinate system allowed each geophysical measurement to be exactly placed spatially. Each block was physically established by staking 20 m ropes parallel to each other on the ground, typically two meters apart. Each rope was marked at meter and half-meter intervals. Instrumentation was then moved in transects along and between each rope allowing measurements to be accurately located (FIG. 1). Half-meter separations between transects were uniformly employed, with data sampled at regular intervals along each. Sample spacing between measurements varied with each instrument, depending on its data acquisition speed. Upon completion of a survey block another was established, usually adjacent to the previous, where survey commenced again. As each survey block was established a detailed map was prepared of all surface-visible features that might influence the geophysical results. This was accomplished by walking along each of the 20 m survey guide ropes and mapping all such features by carefully observing the meter and half-meter marks on the ropes. Mapped features include trees, bushes, surface-visible rocks, depressions and other topographic variations, sidewalks, roads, trails, buildings, flower beds, water spigots, any metallic object, rodent holes, bare patches of earth, and the like. These maps aid the interpretation of the data, for virtually any variation visible on the surface will also cause a subsurface geophysical anomaly. Trees and large bushes, for example, tend to reduce local soil moisture, creating electrical resistance anomalies, while the pipe leading to a water spigot and other metallic items strongly impact GPR and magnetometry findings.

Magnetic Gradiometry

Magnetic gradiometry surveys measure variations in the magnetic field caused by subsurface differences between cultural and non-cultural soils or features. Frequently these differences are subtle owing to minute traces of iron compounds that cause changes in their magnetic susceptibility, the ability of



Figure 1. Instrumentation used for the geophysical surveys at Sylvester Manor. A) FM-36 magnetic gradiometer. B) RM-15 electrical resistance meter with MPX-15 multiplexer and simultaneous 25 cm and 50 cm twin probe arrays. C) 400 MHz GPR antenna with survey control wheel. Note survey guide ropes in A, B.

a substance to be magnetized by the earth's inducing magnetic field. Iron or steel artifacts, in particular, become heavily magnetized in the presence of this field. They tend to yield *dipolar* results, an easily recognized anomaly type expressed as paired positive and negative measurements of extreme value, much like the north and south poles of a magnet. Fired materials, such as baked clays around hearths or burned buildings, also tend to possess elevated magnetic properties owing to *thermoremanent* magnetism that results when iron-bearing soils are subjected to high temperatures (Weymouth 1986). Magnetic gradiometry surveys are rapid compared to most other methods and, consequently, more area was covered by this method than any other at Sylvester Manor (a total of 6,700 m²).

The magnetic gradiometry surveys were accomplished using an FM-36 fluxgate magnetic gradiometer, by Geoscan Research (FIG. 1A). This instrument is very sensitive, capable of 0.1 nT (nanotesla = 10^{-9} tesla) resolution, about one part in a half million of the earth's magnetic field of 50,000 nT in the Northeast (Weymouth 1986). It holds an integrated data logger that allows 16,000 measurements to be stored for later downloading to a computer for processing and analysis. As a gradiometer, the FM-36 does not measure total magnetic field strength; rather, it records differences between measurements made by top and bottom sensors vertically separated by 0.5 m. While both sensors respond equally to temporal variations

in the geomagnetic field caused primarily by the solar wind's interaction with the magnetosphere, the bottom sensor, being closer to the soil, is far more sensitive to its magnetism than the top sensor. By differencing the measurements, temporal effects and diurnal variations are eliminated, leaving only a measurement relevant to the soil at a point on the ground. At Sylvester Manor, four measurements per linear meter were acquired, with transects uniformly separated by 0.5 m, for a sampling density of 8 measurements/m². Depth of investigation for magnetometry is typically regarded at less than 1.5 m (Clark 2000). With the site's many ferrous metal artifacts and features, including a historic cannon, a huge dynamic range in magnetism was present, with measurements exceeding ± 200 nT, the FM-36's practical limit.

Electrical Resistance

Electrical resistance survey methods are sensitive to subtle changes in soils, including moisture, compaction, and porosity differences, and to the presence of buried stone or brick. These methods employ probes to inject an electrical current into the soil. Resistance to that current stemming from subsurface variations is recorded. These methods are particularly sensitive to subsurface contrasts stemming from resistant rock (e.g., foundations or floors), but more subtle soil changes may also be detected (e.g., sediments filling house floors or ditch depressions). Variations in

ground moisture profoundly affect soil resistance, and these changes frequently correlate with subsurface archaeological features (Clark 2000). Resistance surveys require probes to be inserted into the earth, making this method one of the slower and more laborious methods of geophysics. The RM-15 electrical resistance meter, by Geoscan Research, is specifically designed for rapid measurement, however (FIG. 1B). Improved speed is achieved by using a "twin-probe array," a rigid frame holding two probes that is moved about the site and inserted into the ground to acquire measurements. One probe on the frame and one remote probe, connected by wires, form a circuit in which a current is generated and measured. The remaining probe on the frame is connected to a second remote probe that measures voltage. *Resistance in ohms* is then determined by the ratio of voltage to current (by Ohm's Law). The resistance measurement obtained at any locus partially depends on inter-probe distances and geometry, however, so *resistivity in ohm-meters*, a bulk soil property, may also be computed for comparability to other sites and contexts (Clark 2000). Resistance measurements are automatically sensed and recorded in the RM-15's data logger as fast as the frame can be lifted and moved to the next recording station, and a simple mathematical transformation allows resistivity to be estimated.

Resistance surveys can be focused at approximate prospecting depths. With the shallow deposits at Sylvester Manor (indicated by 1999 excavations), two depths of 0.25 m and 0.5 m were investigated, controlled by probe separation distances in the mobile frame (e.g., a target depth of 25 cm is achieved simply by positioning the frame's current and voltage probes 25 cm apart). This was accomplished by using Geoscan's MPX-15 with multiple probes in the mobile frame that allowed 25 cm and 50 cm probe separations to be used for simultaneously prospecting at each of these depths (FIG. 1B). The MPX-15 is a multiplexer, or high-speed switch, which changes between probes, acquires the data, and stores results in a data logger. In all resistance surveys samples were acquired every 0.5 m along transects, which were separated by 0.5 m, allowing 4 measurements/m². Although resistance surveys are slower than magnetometry, nearly as much area was surveyed at Sylvester Manor, with

approximately 6,100 m² acquired in data sets representing the two prospecting depths. With its sandy matrix, rock, and low-lying high-conductivity areas bordering an inlet to the sea, the dynamic range of electrical resistivity was very great, ranging from 120–700 ohm-meters. This forced all of the resistance data in this study to be subjected to a large radius (5 m) high-pass filter (see below) that removed broad geological or moisture trends, allowing improved visualization of potential cultural anomalies.

Ground-Penetrating Radar

GPR methods are sensitive to changes in subsurface materials of any kind, and generally yield a result different from magnetometry or electrical resistance surveys. Most GPR equipment used in archaeology send nearly continuous pulses of radar energy into the ground along the full length of a survey transect. Discontinuities in the subsurface, including stratigraphic contacts, walls, house or pit floors, rubble, or midden deposits, cause the radar energy to be reflected back to the surface. The velocity of this energy varies greatly, depending on *dielectric* properties of the subsurface materials. If velocity can be estimated, then return times of echoes from pulses give information on depth, while amplitudes indicate something of the nature of subsurface changes. The outcome mimics a section or profile along the length of the survey transect. Thus, GPR data in their native form are ideally suited for gaining information in the vertical plane, including stratigraphic relationships (Conyers 2004).

At Sylvester Manor, a Geophysical Survey Systems, Inc. (GSSI) SIR-2000 portable ground-penetrating radar system was employed with a 400 MHz antenna and survey wheel (FIG. 1C). Fifty pulses, or traces, were sent into the ground per linear meter with positioning determined by a survey wheel that controlled trace placement through its movement. The waveform in each trace was quantized in 512 measurements. All GPR profiles utilized a time window of 30 nS (nanosecond = 10⁻⁹ second), which was estimated to allow data acquisition to at least a meter in depth, sufficient for the shallow archaeological deposits at the site (later soil velocity studies estimated maximum penetration at 1.25 m; Kvamme 2001a). Closely spaced parallel transects were separated by 0.5

m that allowed significant reflections in adjacent profiles to be easily cross-correlated for gaining a three-dimensional understanding of the subsurface. Transects were typically 20 m in length, and 2,178 linear meters of transects were covered by GPR in four study blocks measuring from 20×20 m to as small as 8.5×14 m, for a total of 1,089 m². For comparability with the other methods, the GPR data yield 50 traces/m, each with 512 measurements, for 25,600 measurements per linear meter, and 51,200 measurements/m².

The GPR surveys at Sylvester Manor were kept relatively small in area owing to the greater time investment required for set-up, data collection, and particularly data processing, compared to the other geophysical methods. In the six years since that work, significant advances in hardware and software now make large-area GPR surveys more practical to conduct, as recent work has shown (e.g., Kvamme 2006).

Data Processing Methods

The processing of geophysical data is a complex topic, especially when using several survey methods. The data frequently can be treated as imagery, allowing standard image processing algorithms to apply, but specialized procedures are also required that are unique to each type of geophysical data. At an elementary level, the computer processing of geophysical data involves the assembly of the matrices of measurements into proper spatial position, followed by the application of various filters to reduce noise and unwanted data artifacts, and enhance desirable patterns. This processing typically requires a series of ordered steps that include: 1) *concatenation* of data from individual survey units into a single composite; 2) *despiking* of unusually high or low measurements (outliers) that may result from faulty readings (e.g., a probe falling in a rodent hole in resistance surveys); 3) *block balancing* of data between adjacent survey units through adjustments of mean values; 4) *filtering* to smooth statistical noise or to remove broad geologically caused trends; 5) *contrast enhancements* through clipping of high and low values or histogram modification; 6) *interpolation* to estimate additional values for improved image continuity; and 7) *image creation* through assignment of gray or color scales to the data

matrices. Several other specialized processing steps may also be considered as cases warrant (e.g., detrending, shadowing, linear feature enhancement, etc.). These methods were uniformly applied to the magnetic gradiometry and electrical resistance data collected at Sylvester Manor using GEOPLOT software, by Geoscan Research, with some graphic products generated by SURFER (Golden Software). Richards (1986) provides a general introduction to the topic of digital image processing, while Scollar et al. (1990) and Kvamme (2001b) overview the fundamental issues and operations of relevance to geophysical data processing in archaeology.

GPR data are quite different in character and require a very different set of processing methods. In GPR transects the horizontal axis represents distance, and the vertical axis the two-way travel time (TWTT), in nanoseconds, the microwave pulse takes to travel from the surface transmitter into the ground and to reflect from a discontinuity back to the receiver. Obviously, the TWTT is related to depth, and knowledge of how fast the energy travels, or soil velocity, provides a means to estimate actual depth from time (Conyers 2004). At Sylvester Manor, the maximum time window set for the TWTT was 30 nS, which allowed depth penetration to about 1.25 m. A "time-slice" is a special data processing result that literally takes a specified slice of time out of *each* GPR profile and then estimates or interpolates the reflection amplitudes in the distance between adjacent profiles (0.5 m at Sylvester Manor). The result is a *horizontal plan view* of GPR reflection amplitudes across all the profiles in a survey block at a particular TWTT below the surface (for which an approximate depth can be estimated). In general, these time-slices offer much greater interpretability of subsurface structure than the individual vertical profiles, where it can be difficult to recognize archaeological features. Several different time-slices are typically extracted from the profiles simultaneously where the greater the TWTT, the greater the depth (Conyers 2004). GPR profiles were initially processed using RADAN software, by GSSI, to set time-zero positions, remove background banding common to GPR, and apply frequency enhancement filters. Time-slices were generated through the GPR_PROCESS program, developed by Dr. Larry Conyers of the University of Denver.

It is emphasized that much of the labor in archaeological geophysics lies in the processing, analysis, and interpretation of the data. With portable computers some of this work can, and must, be carried out in the field, if only to check that the data are correct before leaving the site, and it represents a large task. Each day the data must be downloaded, backed-up, their quality checked, and the instrument's memories emptied for the next day's work. Preliminary results are printed for further quality checking, to plan future survey locations, and especially to maintain crew morale and interest. Instrument batteries must also be recharged each evening. All of these operations were routinely conducted in the Sylvester Manor surveys.

Soils

The soils at Sylvester Manor are sandy and acidic, which is not surprising considering that Long Island is essentially a sand spit once covered with large tracts of pine forest. In the area of the Manor House there is a well-developed, dark gray A-horizon about 30 cm thick, composed primarily of sandy loam with substantial organic matter (see FIG. 1B,C). Some of the silts, clays, and organic matter that make up the topsoil are probably artificial and imported as a result of centuries of landscaping and gardening. The subsoil is marked by a strong color transition, and is composed primarily of dull yellow sand. These sandy characteristics generally caused high resistivity, especially in higher elevation areas, well drained by clear and ample rainfall. Near Gardiner's Creek and its inlet to the sea that abuts some of the areas surveyed, soil resistivity was comparatively low owing to generally wetter conditions and a likely infiltration of salts into the soil. Analysis of soil dielectric properties for purposes of radar wave velocity in a higher elevation area showed a clear distinction between these soil units. Relative dielectric permittivity was shown to equal $RDP=18.3$ for the topsoil (a value characteristic of moderately conductive clays). $RDP=9.4$ was determined for the subsoil, lying within the range of moist sand (Conyers 2004).

Validation of Geophysical Results

One shortcoming of working in archaeological geophysics is a lack of communication with

project sponsors that frequently occurs after a survey—it is often difficult to learn the nature of results subsequently revealed through excavation. Such information is vital to the archaeogeophysicist, because it contributes to an all-important learning curve that enables better recognition of specific types of archaeological features from the geophysical anomalies they generate. The Sylvester Manor Project staff has been very good in this regard: they have maintained excellent websites showing excavation results, delivered excavation plans and descriptions on several occasions, and shared findings in a symposium in which I participated at the Society for Historical Archaeology meetings in 2003.

In the following sections, it is not possible to review each anomaly and correlate it with excavation findings. Such a task is beyond the scope of this paper, and the cumulative excavation programs of this archaeological project are simply too large. In a few cases, however, known excavation results are presented as a means to demonstrate the validity of inferences or to explain puzzling anomalies. Chapters elsewhere in this volume present excavation findings and refer frequently to the geophysical results, further testifying to its successes and limitations.

Geophysical Surveys at Sylvester Manor

At Sylvester Manor, large contiguous areas were geophysically investigated by magnetic gradiometry and electrical resistance surveys, and several smaller study blocks were examined with ground-penetrating radar. Several goals were pursued in these surveys. An initial one was to determine the utility of geophysical methods for identifying and locating archaeological features at this site. Once this demonstration was successful, the general goal became the mapping of subsurface anomalies over broad areas in several important areas of the site. The vicinity of the 18th-century Manor House received primary focus, where investigations were designed to shed light on the layout and content of the plantation's core area, and reveal specific details about subsurface features for later excavations. The two-acre enclosed historic garden area was also examined in two areas with the hope of revealing and documenting antique garden features.

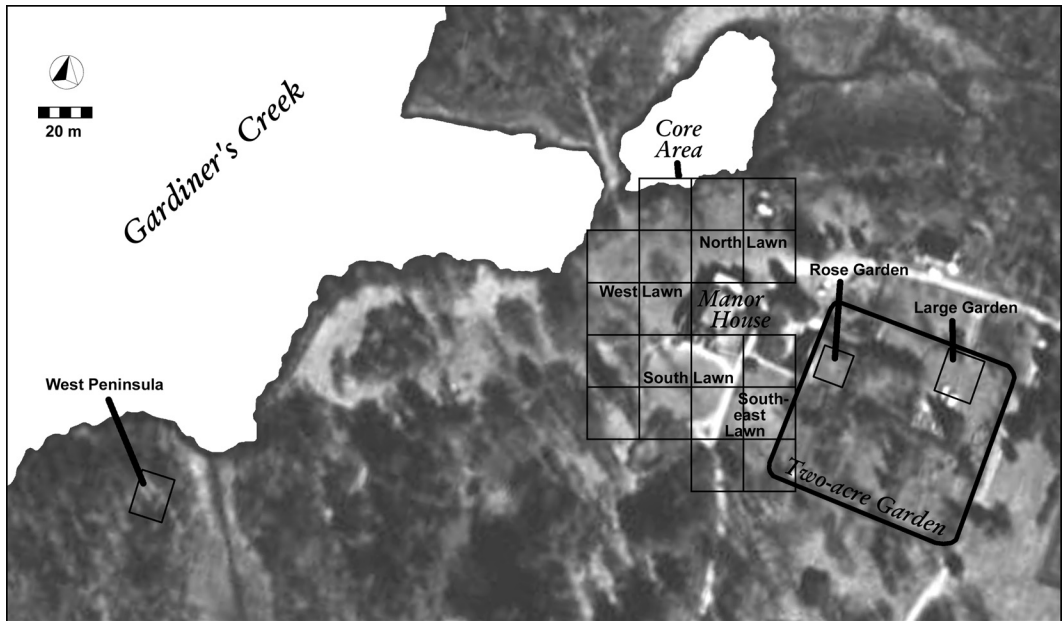


Figure 2. Aerial photograph-plan map of the Sylvester Manor estate showing principal features and geophysical survey areas. Twenty-meter survey grids are shown in the Manor House core area. (Photo date: April 8, 1994).

Minor investigations were also conducted on a remote peninsula in a move of pure prospecting—to locate a rumored grave or possible historic structures (FIG. 2). The following sections summarize the geophysical surveys carried out at Sylvester Manor in each of these three zones, together with principal results, interpretations, and occasional references to archaeological findings revealed by UMass Boston excavations. A full summary of the geophysical investigations has been reported by Kvamme (2001a), with a brief synopsis of significant findings given in Kvamme (2003).

Geophysical Surveys Near the Manor House Core

The Manor House area represents the core of the site where most historic activities were centered. This area therefore received the largest concentration of geophysical surveys in the project, with approximately 5,200 m² of electrical resistance (at two target depths), 5,800 m² of magnetic gradiometry, and 760 m² of GPR in three distinct blocks. Most of this area was covered with a finely mowed lawn, facilitating the surveys. It is subdivided into North, West, South, and Southeast Lawn areas to clarify discussion (FIG. 2).

Electrical Resistance Survey Results

The electrical resistance surveys at Sylvester Manor emphasize contrasts primarily between buried rock (e.g., pavements, foundation stones) and the surrounding soil, but also show differences between individual soil units. In the Manor House core area, the resistance data exhibit a tremendous density of linear and right angle anomalies indicative of intensive cultural use and modification. This occurs at both 25 cm and 50 cm prospecting depths, primarily in the area of the West Lawn (FIG. 2). The 25 cm data tend to illustrate shallower and subtler anomalies, as well as robust ones that extend deeper, coinciding with anomalies in the 50 cm data. The shallower data set also exhibits somewhat better detail or resolution of features. The lower 50 cm data set, on the other hand, tends to show only deeper, massive anomalies; if these features represent architectural remains, a common interpretation in these contexts is that deeper target depths reveal aspects of basal foundations while shallower target depths better indicate remains of superstructures (e.g., wall fragments; see Walker 2000). Whatever the case, because the 50 cm data largely parallel the more detailed 25 cm data in this study area, only the latter will receive focus (FIG. 3A; see Kvamme 2001a for

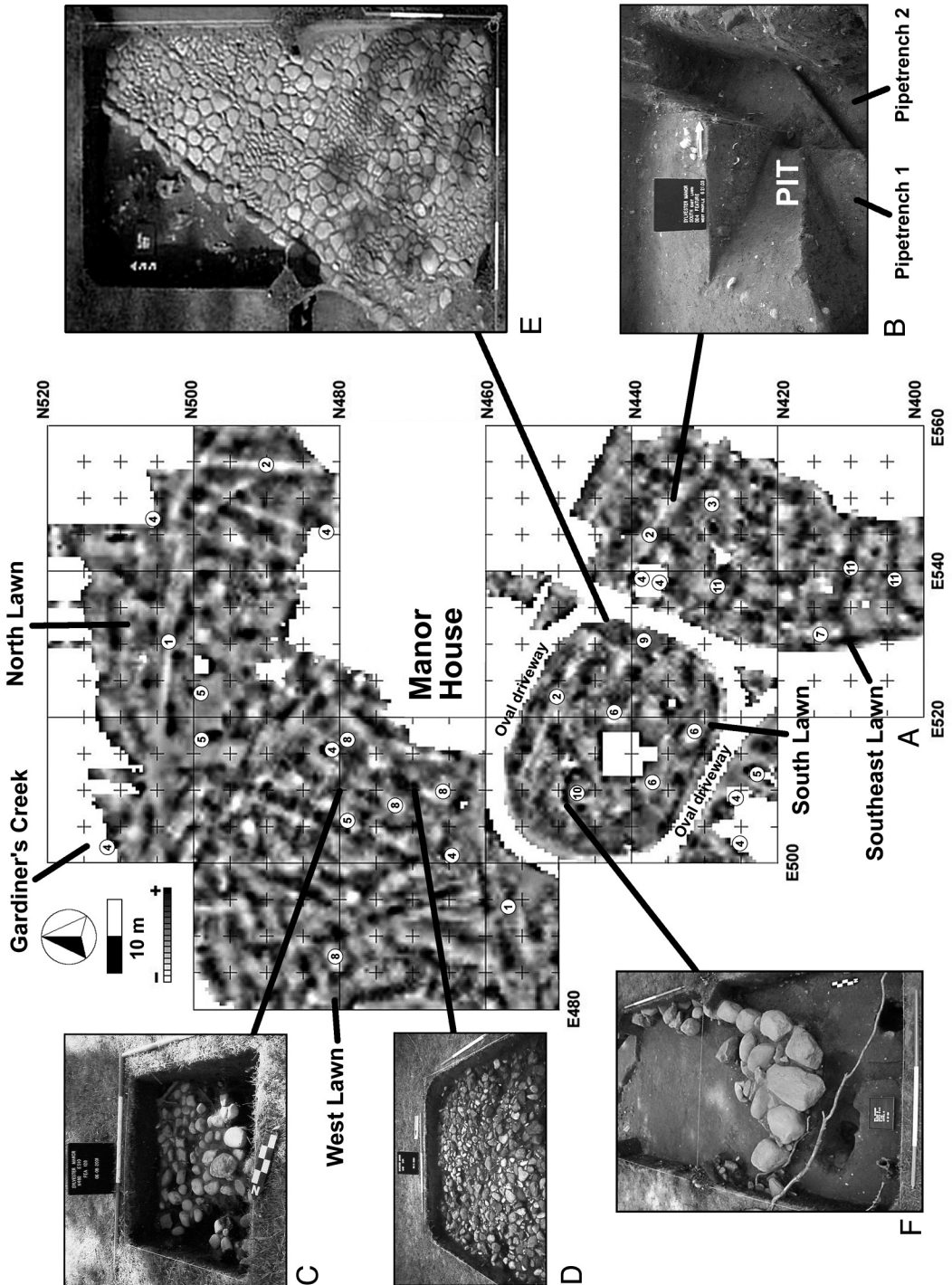


Figure 3. Electrical resistance survey results (25 cm probe separation) and selected excavation findings in the Manor House core area. A) Resistance survey results. B) Pipe trenches, one with a pipe visible, cross-cutting an early historic pit. C, D) Thick matrices of small quartz and quartzite cobbles immediately beneath the surface. E) Stone pavement of small and large cobbles in geometric pattern. F) Alignment of foundation stones. Numbers are keyed to text.

details about other data sets). In the following, parenthetical numbers are keyed to anomalies identified in figures.

Recent features

Many of the anomalies seen in the electrical resistance data are obviously generated by contemporary or recent constructions or features (FIG. 3A). Some, like roads, may have historic origins, but because they are so obvious in the data and on the ground surface they are discussed first with other recent features. A *historic road track* (1), grassed-over and running east-west across the North Lawn (at about N505), is clearly seen in the resistance data as a negative, or low resistance, anomaly. This may be due to a surface treatment with materials like crushed shell or gravel that may act as a mulch allowing greater moisture retention, or perhaps a conductive clay covering. Another *road track* (1) running westward from the oval driveway across the West Lawn (at about N460) is not well indicated in itself, although a surrounding elevated earthen berm illustrates high resistance. A known *pipeline trench* (2) is seen as a strong north-south linear anomaly in the northeastern edge of the North Lawn. A second pipeline trench extends across the northern edge of the South Lawn in a southeasterly direction, and crosses the Southeast Lawn to the east edge of the study area. These pipelines are revealed by low resistance measurements, most likely because they act as moisture traps, making them wetter and lowering resistivity. Massive magnetic anomalies also occur within these trenches, indicating the presence of iron or steel pipes (see below). UMass Boston excavations over the pipeline trench in the Southeast Lawn area have indicated not one, but two overlapping pipelines in closely adjacent trenches. More importantly, both overlay a large pit about seven meters in diameter that dates to the mid-17th century and includes European ceramics and pipe stems diagnostic of that period as well as decorated Native American ceramics (FIG. 3B; see Hayes, FIG. 10, this volume). The low-resistance phenomenon seen in pipeline trenches also accounts for similar measurements in a 1×2 m *backfilled excavation* (3) from the 1999 field season in the Southeast Lawn. On the other hand, *live trees and bushes* (4), if sufficiently large, are known to cause locally high resistance measurements, because they tend to draw significant moisture from the ground. Similarly, *surface rocks* (5) generally exhibit high resistance in their neighborhoods

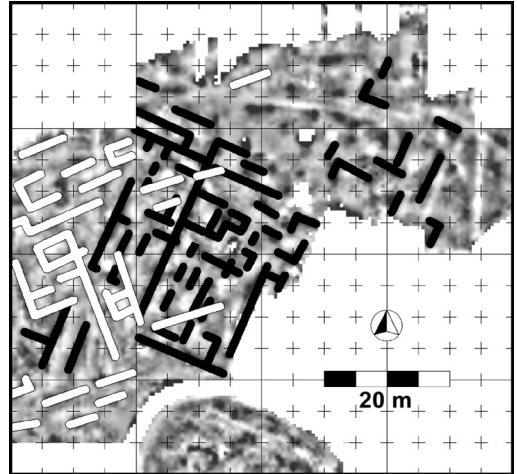


Figure 4. Two rectilinear grid orientations of architectural activity as interpreted in the electrical resistance survey results.

when portions of them yet remain beneath the sod. *Excavation backdirt stains* (6) from the 1999 field season in the South Lawn—areas where earth was mounded during excavations—are indicated by low resistance, probably owing to their increased moisture retention. A *flower bed* (7) indicates a negative anomaly, probably due to a combination of soil compaction, moisture, and soil conductivity differences (fertilized clay-bearing soils may have been introduced). This phenomenon is seen again, particularly in the Rose Garden survey below.

Historic architectural features

Turning to potential historical anomalies in the electrical resistance data, perhaps the most significant features are the plethora of positive linear and right angle anomalies suggestive of architectural features—buildings and other structures in the West Lawn area (too numerous to label in FIG. 3A). Many of the linear anomalies probably indicate former walls, foundations, or lanes. These features quite likely represent the loci of former buildings—perhaps warehouses, administrative, and maintenance facilities—involved with shipping and trading activities via the landing at nearby Gardiner's Creek (see Kvamme 2003). Most of the anomalies exhibit high resistance, suggesting that their sources are composed of materials like brick or stone. Others are very narrow and barely discernable in the data, perhaps resulting from only subtle soil changes. Since brick is a fired material it should also be

revealed by positive anomalies in the magnetic data, but relatively few magnetic anomalies correspond with the resistance results (see below), so brick is largely ruled out. While a small number of surface-visible rocks are igneous and highly magnetic, it is apparent that most of these resistance anomalies do not express a magnetic component, suggesting non-magnetic stone (see below). Excavations by the UMass Boston field teams have verified some of these inferences by revealing several stone alignments and pavements immediately beneath the surface in the West Lawn area (FIG. 3C, D). These features are largely composed of quartz and quartzite cobbles that do not illustrate a significant magnetic contrast with the surrounding soil.

Perhaps the most significant finding suggested by the electrical resistance data is the indication of a *dual orientation* to these likely structural features. In other words, given the rectilinear nature of most of the anomalies, two grid orientations can be discerned in their spatial distributions (FIG. 4). One orientation has its principal axis lying about 30° east of grid north, and the second, to the west, has its principal axis aligned about 30° west of grid north (see Kvamme 2003). This may indicate two principal episodes of building in this area, with a major layout change between the two. Archaeological testing will be required to sort out relationships and relative chronologies in this conjectured evolution of the site.

Other historic features

The electrical resistance data also indicate many anomalies that may represent other historical features of Sylvester Manor (FIG. 3A). Possible *floors or prepared surfaces* (8), with sides measuring from 2–6 m, are suggested in the West Lawn by a number of roughly square to rectangular anomalous areas, coinciding with the previously described lineations. These anomalies are positive and negative in value. The former are most likely composed of stone, but resistant coarse sands or pebbles are possible, while the latter suggest clays or some sort of moisture-retaining sediment. A *stone pavement* (9) was revealed in a 12m² excavation at the eastern edge of the South Lawn by the UMass Boston archaeologists, subsequent to the geophysical surveys (FIG. 3E). This feature is well indicated in the resistance data as a pos-

itive anomaly, and a second similar pavement may also exist on the west side of the South Lawn (FIG. 3A), which is also revealed in a GPR survey (see below). Also in the South Lawn, a *line of foundation stones* (10), indicated by very high resistance readings, was defined and verified by excavation within days of the survey (FIG. 3F). *Historic garden features* (11) may be represented by some of the geometric patterns suggested in the Southeast Lawn, adjacent to the present-day, two-acre garden space that lies to the east (see FIG. 2). As shown below, significant historic garden features were revealed by the geophysical surveys elsewhere on the estate. Positive resistance anomalies in this area might indicate brick or stone alignments bordering former flowerbeds, for example, while negative circular and rectangular anomalies may point to earlier planting beds with reduced soil compaction or increased conductivity caused by moisture content, the use of fertilizers or improved soils. An alternative hypothesis is that some of the lineations seen here may be associated with the original 1652 structure on the site, a possibility suggested by local lore and some historical documentation. Archaeological investigations by UMass Boston have thus far been unsuccessful in locating evidence of such a structure, however (see Hayes, this volume).

Magnetic Survey Results

Anomalies located by magnetic survey are very different from those revealed by electrical resistance or GPR. While magnetic survey data will reveal soil differences owing to variations in iron compounds, these sorts of changes can be very subtle. At historic period sites with a typical abundance of iron artifacts, these subtleties are often “lost” behind a general litter of pronounced magnetic anomalies caused by those artifacts. Furthermore, because magnetic surveys are also very sensitive to well-fired materials, such features as hearths, burned areas, and fired artifacts like bricks tend to be strongly revealed as well. In some cases, buried rock alignments can be seen in the data when their larger magnetic properties significantly differ from the surrounding soil. At Sylvester Manor, with several hundred years of intensive occupation during the historic period, all of these circumstances are present. The magnetic survey data identifies the loci of individual

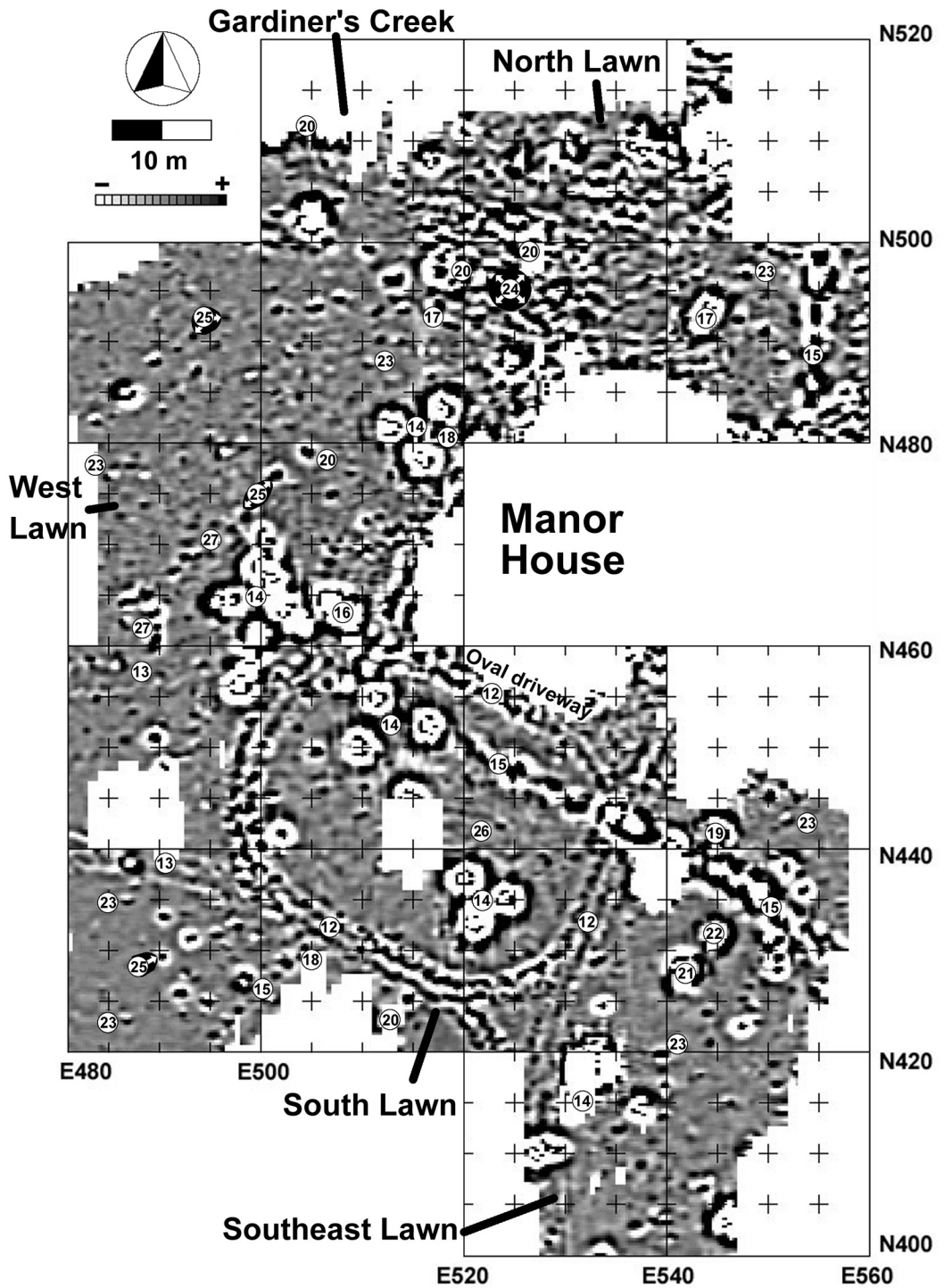


Figure 5. Magnetic gradiometry survey results in the Manor House core area. Numbers are keyed to text.

buried iron artifacts and a midden or dumping area, and some tenuous linear alignments likely caused by buried rocks are suggested. In general, the magnetic survey data in the core area is uninformative about the structure and layout of the underlying historic complex lying only centimeters below the surface that was revealed by the electrical resistance surveys, however (FIG. 3A). The magnetic gradiometry survey results for the Manor House core area are illustrated in Figure 5.

Recent features

Many of the magnetic anomalies seen in Figure 5 are generated by modern or recent artifacts or constructions, although some may have historic origins. *Asphalt covered roads* (12) are readily apparent because of the high magnetic properties of this material. Several *other roads* (13), possibly dating to historic periods, are also revealed in grassed-over areas, probably owing to the removal or shifting to the side of magnetically enriched topsoil. Some of the most prominent anomalies are *tree support-wire anchors* (14), essentially large steel stakes placed in the ground, usually occurring in triplets. Centrally located trees are affixed to the anchors by steel wires that assist their vertical growth. Several iron, steel, or ceramic *pipelines* (15) for water or sewage are expressed by linear series of robust, contiguous, dipolar anomalies. The *Manor House*, itself, can be characterized as a magnetic anomaly stemming from iron or steel used in its construction, magnetic foundation stones, and electromagnetic fields associated with house wiring. Their net effects generate many anomalies adjacent to the house. Several miscellaneous anomalies in the data are also easily explained including a historic cannon (16), drainpipes (17), water spigots (18), a flagpole (19), magnetic surface rocks (20), a wire fence (21), and a magnetic stone monument (22; FIG. 5).

Historic features

The remaining magnetic anomalies in Figure 5 probably represent a combination of historic and recent iron or steel artifacts, burned areas, or magnetically susceptible stone or brick. For many, excavation will be necessary to identify the sources of these anomalies and their periods of association. Aside

from the tree anchors and roads, perhaps the most apparent anomalies arise from *ferrous metal artifacts* (23), seen as a general "litter" of dipolar anomalies across the area. A large portion of them probably represent pre-modern artifacts, although some undoubtedly are of more recent origin. A large *midden area* (24) may be discerned in the North Lawn, where a jumble of large and dipolar magnetic anomalies are seen in close proximity, covering an oval region measuring about 20×30 m. UMass Boston excavations have confirmed this area to be a historic dumping ground or midden, composed of magnetically susceptible building stones, brick, burned areas, and containing assorted ferrous metal debris (see Hayes, this volume). A number of "point" anomalies in *linear alignment* (25) are also apparent in the data, particularly in the West Lawn area (FIG. 5). Some correspond with stone pavements or building foundations revealed by electrical resistance surveys (partially confirmed by excavation, FIG. 3C, D). A few of these stones exhibit high magnetism, creating the visible anomalies and, indeed, one igneous rock (20) shows itself through the sod and forms part of one alignment. *Linear alignments* (26) on the South Lawn may point to former walls of structures; extensive excavations in this area have revealed many such linear features (FIG. 1B, C; 3G). Several *non-linear alignments* (27) perhaps indicate surrounding walls of structures in the West Lawn area, made visible by magnetic rock or perhaps intensive firing. Several of these features are coincident with findings in the electrical resistance survey (FIG. 3A).

GPR Study Blocks

Three small areas were surveyed by GPR in the Manor House core area to further investigate the nature of subsurface features discovered by other methods. Two of these areas offer results of particular interest.

West Lawn

This study block measures 20×20 m and is located in the core zone of linear and rectilinear resistance anomalies (FIG. 3A). It is represented by 40 GPR profiles. The area surveyed captures the transition between the two principal orientations of alignments discussed previously (FIG. 4), and it was hoped that more intensive

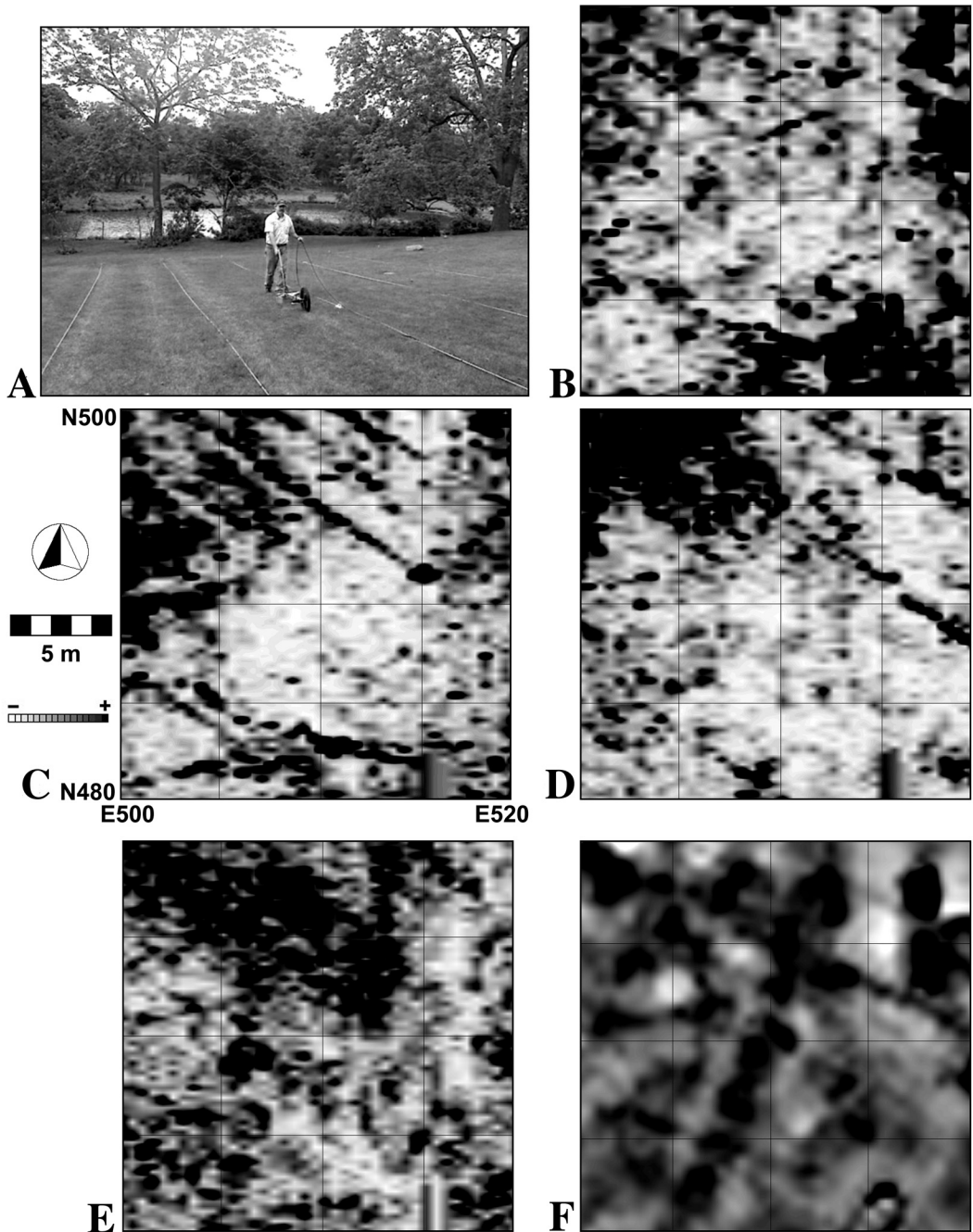


Figure 6. GPR and other results in the West Lawn of the Manor House core area. A) Photo of survey underway. B) 0–7.5 nS (20 cm) time slice. C) 7.5–15 nS (20–53 cm) time slice. D) 15–22.5 nS (53–90 cm) time slice. E) 22.5–30 nS (90–127 cm) time slice. F) Electrical resistance data (25 cm probe separation).

study would help to sort out relationships (e.g., vertical ones) between the dual patterns. The entire survey area exhibited few features on the surface and was covered by a mowed lawn (FIG.

6A). Several dozen time slices were generated from the GPR data, ranging from one to several nanoseconds in thickness and representing TWTT between 1–30 nS. Four representative

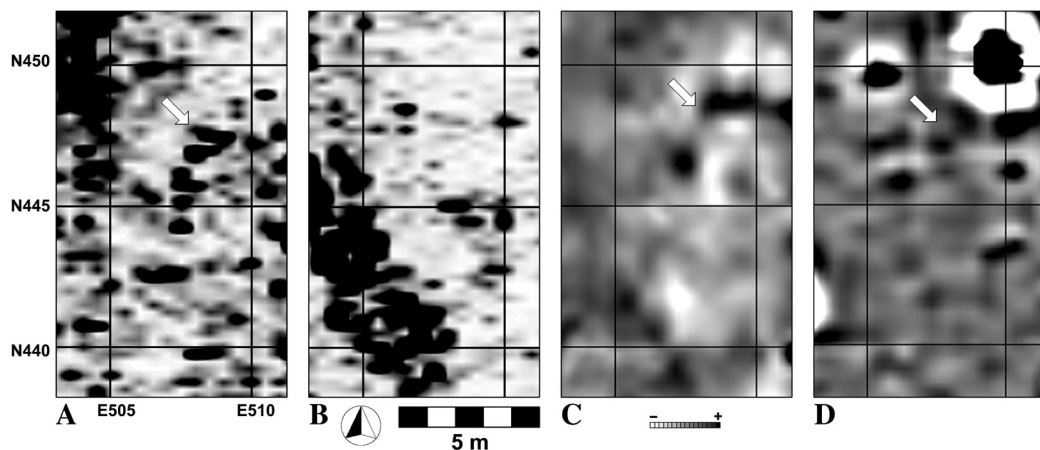


Figure 7. GPR and other results in the South Lawn of the Manor House core area. A) 8 nS (22 cm depth) time slice. B) 17 nS (60 cm depth) time slice. C) Electrical resistance data (25 cm probe separation). D) Magnetic gradiometry results with large anomaly in upper right caused by a steel tree anchor. Arrows point to various expressions of a stone wall illustrated in Figure 3F.

ones are presented in Figure 6B-E: (0–7.5 nS (to about 20 cm depth), 7.5–15 nS (20–53 cm), 15–22.5 nS (53–90 cm), and 22.5–30 nS (90–127 cm). Also shown are the corresponding 25 cm probe-separation resistance data, for comparison (FIG. 6F).

These data offer a very different picture of the study block, and perhaps a surprising one. The electrical resistance data show numerous highly resistant lineations, suggestive of and in some cases verified to be of rock (FIG. 3, 5F). These very same anomalies do not generally appear in the GPR data (FIG. 6B-E), although a broad anomalous area in the deepest slice appears to parallel a high resistance feature, and perhaps indicates a broader floor or surfaced area (FIG. 6E). The lack of agreement between the two geophysical surveys may be explained by the fact that electrical resistance measurements quantify conductivity changes in the soil; in GPR, conductivity variations primarily affect signal transmission and attenuation (Conyers 2004). The primary cause of GPR anomalies is gross changes in the dielectric properties of subsurface materials—their ability to temporarily store an electrical charge. It is hypothesized that the small quartz and quartzite cobbles that make up some of the highly resistant features do not possess significant dielectric differences from the sandy soils in which they lie, and therefore do not generate pronounced GPR reflections. Other very narrow lineations are obvious in some

of the GPR slices, but are oriented at a very different angle across the survey area (FIG. 6B-D). Limited archaeological investigation has shown them to represent pipelines for lawn sprinkler systems.

South Lawn

This small GPR study block is located on the west side of the South Lawn, measures 8.5 × 14 m, and represents only 17 profiles. It was investigated because it was to be a focus of excavation within a few days and it was sited adjacent to an open 6 × 6 m excavation block of 1999. The 1999 excavation allows visual correspondence between features apparent in it and the GPR data (FIG. 1C), and the subsequent 2000 excavations provide limited ground validation of other results. Several horizontal time slices were generated from the GPR data, and two are presented here (FIG. 7A, B): one at 8 nS (about 22 cm depth) and the other at 17 nS (about 60 cm depth). Also shown are the corresponding 25 cm probe-separation electrical resistance (FIG. 7C) and magnetic gradiometry (FIG. 7D) results.

A broad rectangular region stands out in the deeper GPR time slice (FIG. 7B), measuring approximately 4 × 10 m in the area surveyed. The corresponding electrical resistance data hint at the edge of this anomaly and generally indicate elevated measurements over much of its area (FIG. 7C). This anomaly may represent another stone pavement similar to the one on

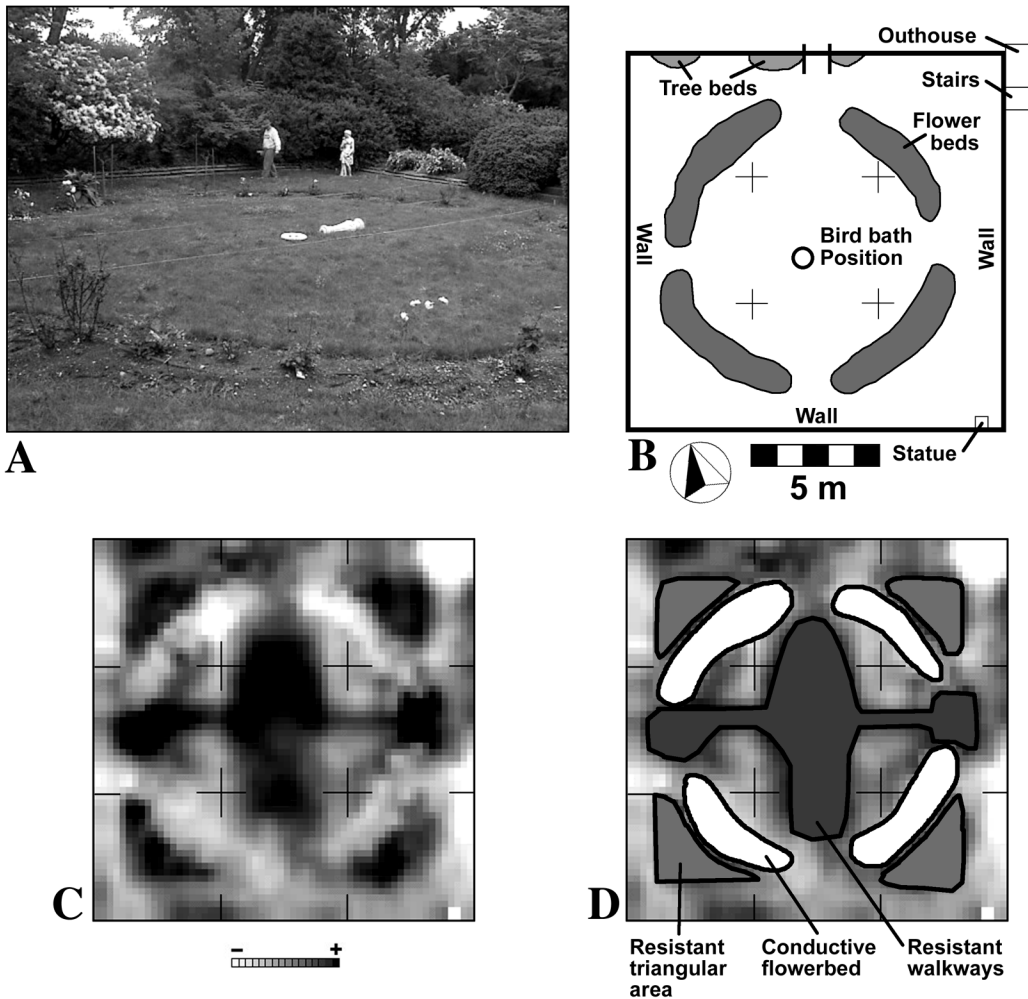


Figure 8. Geophysical results in the Rose Garden. A) View (to the southeast) of the magnetic gradiometry survey underway. B) Plan of garden at time of survey. C) Electrical resistance results (25 cm probe separation). D) Interpretation of results.

the other side of the South Lawn (FIG. 3E), or perhaps a floor with a different fill. Also fairly clear in the upper time slice is a curvilinear string of anomalies about 7 m long (FIG. 7A) that corresponds with anomalies seen in the electrical resistance (FIG. 7C) and magnetic gradiometry (FIG. 7D) data. This robust anomaly was later revealed by excavation data to be an alignment of stone of apparently high magnetic susceptibility (FIG. 3F). Its somewhat shifting location in these data sets is explained by the coarser sampling densities of the magnetic gradiometry and particularly the electrical resistance data.

Garden Surveys

The archaeology of gardens, and the cultural meanings they reflect, has grown to be an important domain of historical archaeological pursuits (e.g., Miller and Gleason 1998). At Sylvester Manor, two garden surveys were conducted using geophysical methods. Given the length of the historic occupation at this site, and associated gardening and landscaping practices, it was anticipated that antique garden features might well be revealed through geophysics, and this proved to be the case. Unfortunately, no subsequent archaeological investigations have yet been carried out in

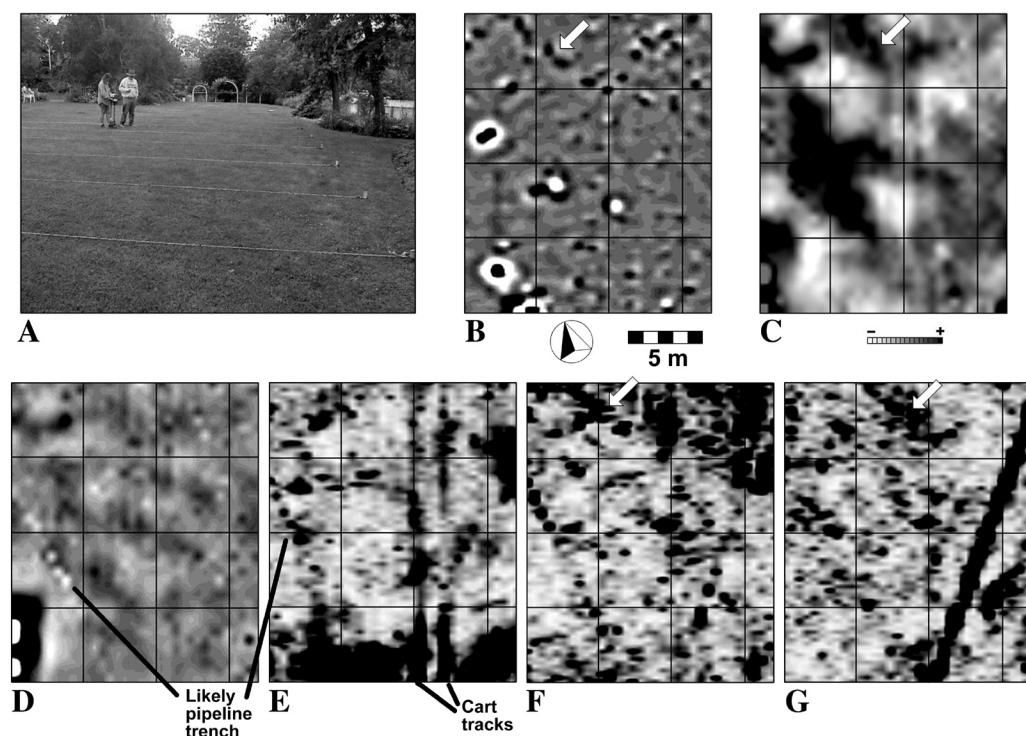


Figure 9. Geophysical findings in the Large Garden Area. A) Photo of electrical resistance survey underway. B) Magnetic gradiometry results. C) Electrical resistance results (25 cm probe separation). D) Electrical resistance results (50 cm probe separation). E) 2–9 nS (25 cm) GPR time slice. F) 9–16 nS (25–58 cm) time slice. G) 16–23 nS (58–93 cm) time slice. Arrows point to common anomalies interpreted as former flowerbed edging.

these areas, so interpretations must be taken as provisional at this time.

Small Rose Garden

A small survey was carried out within the confines of an approximately 15×15 m rose garden (FIGS. 2 and 8). Magnetic gradiometry and electrical resistance surveys were employed, the latter using 25 cm and 50 cm probe separations. A plan of the garden as it existed in 2000, showing the loci of four flowerbeds, walls, and a birdbath, is given in Figure 8B. The magnetic gradiometry survey (not illustrated) revealed little of interest aside from identifying several ferrous metal targets, including what are likely iron supports in the abutting western wall (Kvamme 2001a). The shallow electrical resistance data, however, indicated a garden landscape very different from the present one. In addition to the four extant flowerbeds, which exhibit low resistance (perhaps due to regular watering and improved soils containing conductive clays),

four abutting triangular zones of high resistance exist, as well as two linear features of high resistance, one wide and the other narrow, that cross the central garden space at right angles (FIG. 8C). The latter can only represent walkways of cobble, gravel, or perhaps sand (all resistant materials—brick is ruled out due to the absence of corresponding magnetic anomalies). We can only speculate on the nature of the triangular features; they may represent former areas paved artistically with cobbles, for example, even though the areas in question are presently under sod and look no different from surrounding regions (FIG. 8A). An interpreted map based on the geophysical findings is given in Figure 8D.

Large Garden Area

The largest open space within Sylvester Manor's formal garden (FIG. 2) was subjected to more intensive geophysical investigations within a 20×17 m area. Magnetic gradiometry, electrical resistance with 25 cm and 50

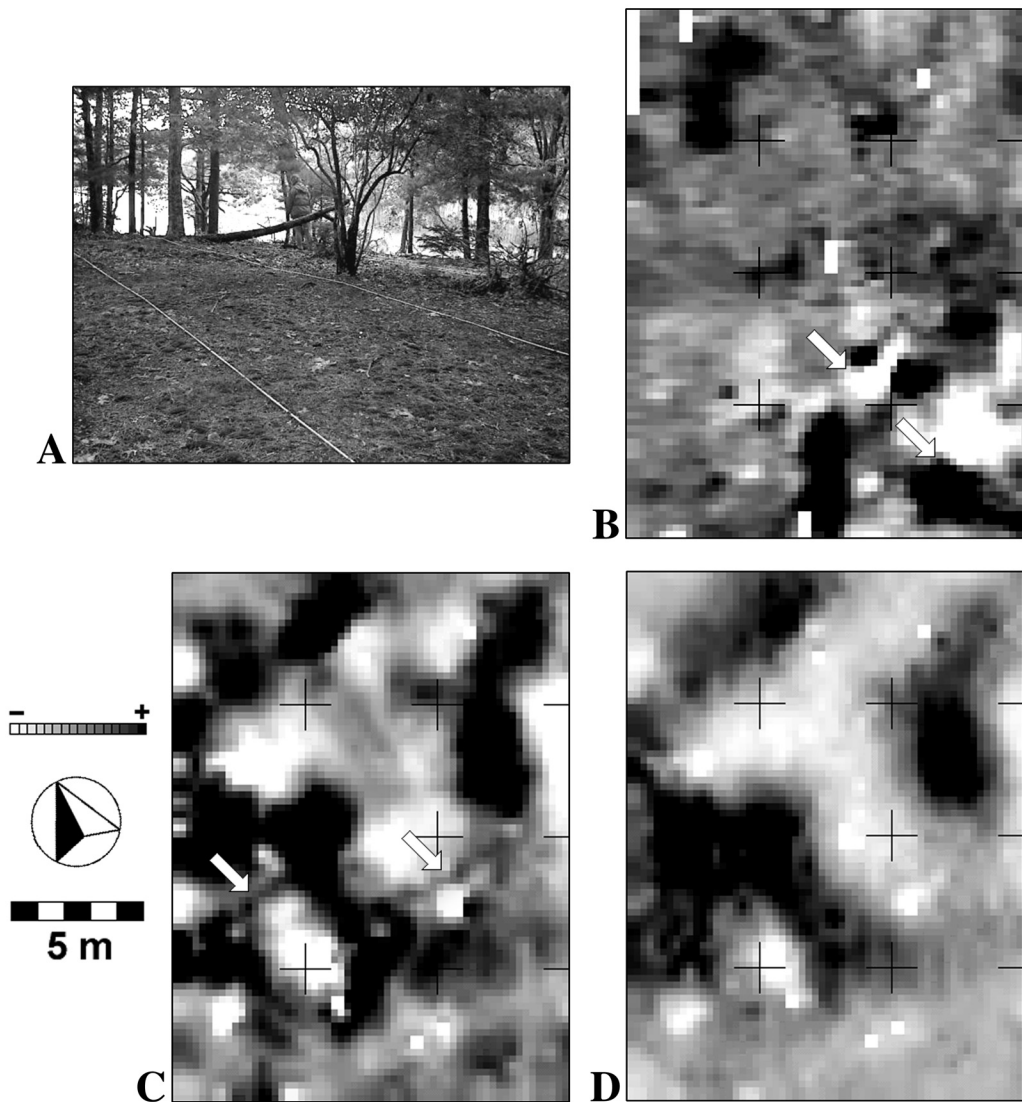


Figure 10. Geophysical surveys in the West Peninsula. A) Photo of electrical resistance survey underway. B) Magnetic gradiometry results (arrows point to large dipolar anomalies signifying iron artifacts). C) Electrical resistance data (25 cm probe separation), with arrows pointing to lineations interpreted as cultural in origin. D) Electrical resistance data (50 cm probe separation).

cm probe separations, and GPR surveys were undertaken, each yielding culturally significant anomalies under the manicured lawn (FIG. 9A). The magnetic gradiometry survey revealed a typical distribution of ferrous metal artifacts (as dipolar anomalies) but significantly, zigzagging linear alignments of monopolar anomalies are also indicated near the north end of the survey block (arrow, FIG. 9B). They are interpreted as likely flowerbed edging stones or bricks that

indicate the flowerbeds that currently exist a few meters to the north once extended further to the south, and in a very different pattern (the current ones have a linear edge, FIG. 9A). Corresponding, but less distinct, anomalies occur in other geophysical data sets (arrows, FIG. 9C, F, G).

The GPR survey of the area was also informative. A time slice map representing 2–9 nS TWTT (to about 25 cm depth) reveals two par-

allel linear anomalies (FIG. 9E), interpreted as a former cart track especially because they point to an extant gate lying only a few meters to the north (this track is also faintly indicated in the 25 cm electrical resistance data, FIG. 9C). The second time slice from 9–16 nS (about 25–58 cm in depth) shows a region of robust anomalies along the north edge (FIG. 9F) that may be associated with the hypothetical flowerbeds suggested by the magnetometry survey. The third time slice (16–23 nS, about 58–93 cm in depth) indicates a very robust linear anomaly to the southeast, interpreted as a buried pipeline or culvert (FIG. 9G). A more detailed analysis of the GPR data shows this anomaly to slope downward, dropping at least 30 cm, from south to north. Interestingly, it cannot be made of iron, steel, or ceramic, because there is absolutely no indication of it in the magnetometry data (FIG. 4 9B). Wood, concrete (but without iron mesh), non-ferrous metal (lead, copper), or a magnetically neutral stone are possible candidates for its construction.

The electrical resistance data generally reveal indistinct anomalies (FIGS. 9C, D), but give hints of patterns conforming to the magnetic anomalies along the north edge—the two-track feature seen in GPR. They also indicate yet another anomaly interpreted as a pipeline trench that is very narrow and linear in the lower left of the 50 cm probe-separation data (FIG. 9D). Again, it is probably the higher moisture in the pipeline trench that is detected (causing lower resistivity), pointing to a pipeline of non-ferrous material, possibly lead (since no indications are seen magnetically). Hints of this feature can also be seen as a less distinct GPR anomaly in the highest two time slices (FIGS. 9E, F).

West Peninsula

The West Peninsula is a wooded area located about 200 meters from the Manor House on the other side of a small tidal marsh (FIG. 2). Local lore asserts that Nathaniel Sylvester (one of the brothers who established the original plantation in 1651, see Mrozowski and Hayes, this volume) may be buried there, but it also may have contained structures or been the site of specialized historic activities. Magnetic gradiometry and electrical resistance surveys with 25 cm and 50 cm probe

separations were carried out in a 20 × 15 m region. This area contained several large trees, but the underbrush was clear-cut prior to the surveys to facilitate instrument passage (FIG. 10A). Results in this area were not very conclusive, although anomalies were indicated, several of which are likely cultural in origin. The magnetic gradiometry survey revealed several pronounced dipolar anomalies that can only point to massive iron artifacts (arrows, FIG. 10B). Several broad areas of high magnetic value may indicate regions where substantial firing of the soil occurred. Both resistance surveys show similar broad patterns of high and low resistance that are difficult to interpret (FIG. 10C, D). They easily could represent cultural modifications to the landscape resulting from construction activities (e.g., floor areas, or soil mounding adjacent to buildings), but they might also represent natural phenomena such as ground disturbances from tree throws. Significantly, the shallow resistance data indicate two parallel linear features (arrows, FIG. 10C) that are most likely associated with former structures (such lineations rarely occur in nature). In short, the geophysical findings strongly suggest substantial human activities in this area.

Two small test excavations subsequent to the surveys found few historic artifacts in this area, although they included brick and nails suggestive of constructions. A higher volume of pre-contact material was located, however, in the form of quartz debitage and projectile point fragments, raising the possibility of a pre-historic component at this locus, and possible prehistoric structures (see Hayes, this volume).

Conclusions

Intensive geophysical studies employing magnetic gradiometry, electrical resistance with two target depths of investigation (25 cm and 50 cm), and ground-penetrating radar were carried out within several distinct study areas of the Sylvester Manor estate during June of 2000. The results of this work indicate numerous subsurface anomalies that must be cultural in origin, testifying to the intensity of use of this landscape. The findings have pointed to historic roads, a midden area, a complex of likely structures composed of floors, walls, and lanes between them, individual walls

and pavements, and former garden features. Archaeological work conducted since those surveys has validated the presence of some of these features, and clarified the identification of others. The Sylvester Manor Project has demonstrated that geophysical surveys can make an important contribution to archaeological projects of this nature, where occupation is on-going and intensive modern landscaping has occurred. The geophysical results have allowed features of potential interest to be identified for excavation, creating cost savings because they can be placed at specific locations with a higher probability of significant return. The overall pattern of geophysical anomalies, whether pointing to individual roads, walls, garden features, or possibly entire complexes of historic structures, offers a form of information about settlement layout and structure that is significant in itself, yielding a data set with interpretive potential. The archaeological excavations have also been important to the geophysical interpretations, allowing them to be fine-tuned and better understood, as realizations of what actually lies in the ground can be matched with measurements made by various sensors. In short, geophysical surveys linked with traditional fieldwork activities yield lines of evidence that allow superior interpretations of the past.

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